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Editorial Comment

Dynamic Subaortic Obstruction: A Disease of the Mitral Valve Suitable for Surgical Repair?*

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Role of the mitral valve in subaortic obstruction. Because the left ventricle, in contrast to the right, has no separate inflow and outflow tract, it has to be converted from an inflow chamber in diastole to an outflow chamber in systole (1). This conversion is achieved by the anterior mitral leaflet switching like a relay from the septum toward the posterior wall, where it is tethered in systole by the papillary muscles. These muscles arise posteriorly and restrain the coapted leaflets below the outflow stream, which can proceed unimpeded; any disruption of this tethering mechanism, therefore, has the potential to allow the leaflets to move anteriorly and obstruct outflow. Such changes are well recognized to occur in hypertrophic cardiomyopathy, in which anterior displacement of the papillary muscles and mitral leaflet elongation diminish the effective tethering of the leaflets posteriorly and provide sufficient leaflet mobility to allow systolic anterior motion (SAM) of the leaflets, obstructing the outflow tract (2–11). Obstructive hypertrophic cardiomyopathy is therefore as much a disease of the mitral valve as it is of the myocardium. As a consequence, particularly in patients regarded as suboptimal candidates for septal myectomy, attempts have been directed to abolish outflow tract obstruction and mitral regurgitation by mitral valve surgery, the most definitive approach being excision of the native valve and replacement by a prosthesis (12). To avoid the limitations of prostheses, mitral valve plication has recently been introduced by McIntosh et al. (13) as an adjunctive procedure for patients judged at operation to be at increased risk for suboptimal hemodynamic results from septal myectomy alone. The decision to reduce anterior leaflet width by plication is guided by intraoperative and preoperative echocardiography and direct observations of an enlarged and elongated anterior mitral leaflet persisting to prolapse into the outflow tract with septal contact despite apparently adequate muscular resection. This approach has yielded excellent hemodynamic and symptomatic results comparable to those of myectomy alone in patients without substantially enlarged mitral leaflets (13).

Anterior mitral leaflet extension. Whereas mitral valve plication reduces anterior leaflet size and thus follows the logic of pathoanatomic and echocardiographic studies of the mechanism of SAM, Kofflard et al. (14) in this issue of the Journal propose the exact opposite—horizontal anterior mitral leaflet extension—and with apparently no less impressive results. In a series of eight patients in whom the surgeon considered myectomy alone unlikely to yield optimal results, a glutaraldehyde-preserved autologous pericardial patch was inserted into the anterior leaflet, in a modification of a technique initially developed by Carpentier to treat mitral regurgitation in rheumatic valvular disease and bacterial endocarditis with perforation (15).

Why does it work? As suggested by the authors, the patch extends across the bending point of the buckling anterior leaflet and may stiffen it, preventing SAM. If this is the principal mechanism, simply sewing a pericardial patch onto the central portion of the leaflet would be expected to do the job without changing leaflet dimension. The basis for another explanation is the observation that SAM is typically greatest at the leaflet center (2,3,5,7), consistent with increased slack of the related chordae (e.g., created by inward or central displacement of the papillary muscle tips, as seen in hypertrophic obstructive cardiomyopathy). The authors therefore propose that inserting the central patch may displace the chordae inserting into the central leaflet laterally, thus stretching them and increasing leaflet tethering. Further, taking the anterior leaflet margins, which have been incised along a straight line, and deforming them to follow the longer elliptical outline of the patch should make the leaflet slightly shorter because leaflet area and mass remain the same; this change would therefore reduce the slack needed to produce SAM.

An alternative hypothesis would be the additive beneficial impact of increased leaflet area once the streamlines of flow have been normalized by septal myectomy. In the presence of a hypertrophied basal anterior septum bulging into the cavity, blood flow cannot take the direct route from the apex to the outflow tract, but must circumvent the septum (Fig. 1). The streamlines of flow are therefore curved and may hit the anterior leaflet on its posterior surface, pushing it toward the septum. Once normalization (straightening) of the intraventricular streamlines has been achieved by subvalvular myectomy, flow is directed onto the anterior surface of the mitral leaflets, as in normal hearts; in this case, increasing leaflet area by horizontal extension (which probably does not increase leaflet slack) will be beneficial in preventing SAM and mitral regurgitation because the anterior leaflet is then pressed

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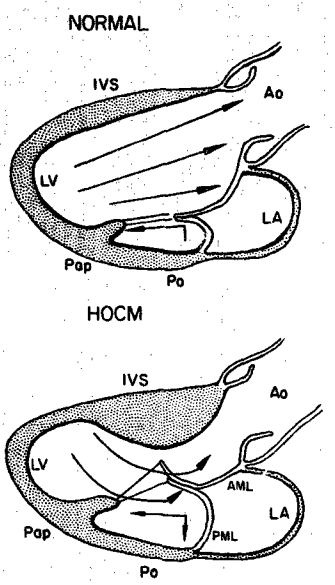

Figure 1. Top, In addition to the force generated by the papillary muscles (directed apically and posteriorly, as shown by the **arrows** below the mitral valve), the flow that is directed onto the anterior surface of the mitral leaflet contributes to keeping the mitral valve posteriorly with a force that equals left ventricular pressure times the area of the leaflet exposed to that pressure. **Bottom,** Because of a hypertrophied basal anterior septum bulging into the cavity, blood flow cannot take the direct path from the apex to outflow tract, but necessarily must circumvent the septum. The streamlines of flow are therefore curved and may hit the anterior leaflet on its posterior surface, dragging it toward the septum; leaflet mobility to follow the forces of the flow field is facilitated by abnormal mobility of the mitral valve due to leaflet elongation and anterior displacement of the papillary muscles. AML = anterior mitral leaflet; Ao = aorta; LA = left atrium; LV = left ventricle; HOCM = obstructive hypertrophic cardiomyopathy; IVS = interventricular septum; PML = posterior mitral leaflet; Po = posterior wall of the left ventricle.

posteriorly by a force that is proportional to the leaflet area exposed to flow. In fact, a flow stream directly impacting on the anterior surface of a tethered mitral leaflet in vitro actually maintains its posterior position and effectively opposes the lift or Venturi force created by a higher velocity outflow stream not impacting on the leaflet surface (16). The practical implication of this mechanism is that horizontal leaflet extension would be helpful after septal myectomy (in a synergistic manner) but would not necessarily reduce SAM without it, whereas mitral leaflet plication has the potential to reduce or even abolish SAM independently; leaflet stiffening caused by the patch, of course, would reduce SAM independent of myectomy as well.

Another observation of mechanistic interest is that mitral regurgitation, which was more severe before operation in the group undergoing leaflet extension, was abolished more effectively by providing greater leaflet area; this is consistent with previous observations, both in vitro and in patients, that increased leaflet contact area reduces mitral regurgitation for a given degree of SAM (11,17,18).

Does it work? Proving the value of an additional mitral valve intervention after myectomy would require either demonstrating more effective results with than without mitral valve surgery (either in the same patients or in matched groups, not chosen in the present study) or demonstrating good hemodynamic results with additional mitral valve surgery in patients known to do poorly with myectomy alone, as the authors set out to do. It is not clear, however, that such proof is available on the basis of the selection process in this study, which related to the impression regarding expected hemodynamic outcome. Obviously, the severity of mitral regurgitation favored mitral valve extension. Other conditions generally favoring mitral valve surgery, such as limited septal hypertrophy, although mentioned in the methods and discussion sections, did not appear to play an actual role: There was no difference in the range of septal thickness in the group with and without additional mitral leaflet extension (20 to 35 mm vs. 20 to 33 mm). Moreover, in the group undergoing additional mitral leaflet extension, myectomy was significantly more effective in reducing septal thickness (19 ± 4 mm vs. 22 ± 4 mm, $p < 0.05$, Table 2 [14]). In view of the limited number of patients, as the authors note, it cannot be excluded that at least some of the beneficial effect attributed to the additional mitral leaflet extension was actually caused by a more effective myectomy in the leaflet extension group. No information is provided as to whether there was a difference in mean mitral leaflet area between the two groups, although it is mentioned that all patients in both groups had clearly enlarged leaflets, and whether differences in leaflet length and area could potentially be valuable for selecting the appropriate procedure. Finally, it is not clear why postoperative functional class was better in the leaflet extension group despite a comparable hemodynamic result. The differences in functional class cannot all be related to decreased residual mitral regurgitation (Table 1 [14]). It is even conceivable that the effect of medication (such as antiarrhythmic agents or a combination of beta-adrenergic blocking agents and calcium antagonists, which has been shown to increase pulmonary artery pressure significantly without any beneficial effect compared with each drug alone [19]) may have contributed to the decreased functional capacity of the patients undergoing myectomy alone, who were taking more medications postoperatively (Table 2 [14]). A placebo effect in patients who know they have undergone an "improved" procedure also cannot be excluded without objective exercise testing, which can safely be performed in these patients (20,21), particularly after relief of outflow tract obstruction.

Is it necessary? Subvalvular myectomy has been shown to be an effective treatment for symptomatic patients with obstructive hypertrophic cardiomyopathy refractory to medical treatment that can be performed with low mortality and morbidity in experienced hands, yielding excellent symptomatic and hemodynamic long-term results, with an experience of >25 years (22–26). A subset of patients, however, may be

difficult to manage without additional mitral valve surgery, even in experienced hands (13,14), and could therefore benefit from mitral leaflet plication or extension. Definite proof of the superiority of combined myectomy and mitral valve repair would require a staged approach, with assessment of hemodynamic variables by intraoperative echocardiography after myectomy alone (off bypass) and then after the additional mitral valve repair. (Such multiple bypass times are routinely used in some centers [27] for optimizing myectomy by intraoperative echocardiography and thus do not involve the ethical problems posed by a randomized study in this context.) Quantification of mitral leaflet geometry by intraoperative echocardiography could potentially help us to develop clearly defined indications for mitral valve repair as well as guide the procedure. Nevertheless, the study by Kofflard et al. (14) is consistent with growing evidence that structural abnormalities of the mitral apparatus can play a primary role in causing SAM and dynamic subaortic obstruction (2–11,28,29). In hypertrophic cardiomyopathy, SAM can be viewed as the result of an abnormal mitral valve apparatus exposed to an abnormal flow field; leaflet extension after myectomy addresses both of these factors. Systolic anterior motion after mitral valve repair for myxomatous prolapse can also be related to slack leaflet portions interposed into the outflow stream because the posterior leaflet is elongated and shifts the coaptation point anteriorly (30–33). These observations are consistent with lessons learned from experimental and computational models studying the interaction of the mitral valve and outflow stream (5–7,16,34–38). This increased understanding has direct practical implications for surgical management, and it is our expectation that detailed cardiac ultrasound imaging of the underlying anatomy (39) will allow new techniques to be applied most effectively to the individual patient to provide the most normal function and the greatest benefit.

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